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# Parameters of explosives detection through tagged neutron method

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ABSTRACT

The potentialities of tagged neutron method (TNM) for explosives detection are examined on the basis of an idealized geometrical model. The model includes ING-27 14 MeV neutron generator with a built-in α-detector, a LYSO γ-detector and samples of material to be identified of approximately 0.3 kg each: explosives imitators (trinitrotoluene - TNT, tetryl, RDX and ammonium nitrate), legal materials (sugar, water, silk and polyethylene). The samples were unshielded or shielded by a paper layer of various thicknesses.

The experimental data were interpreted by numerical simulation using a Poisson distribution of signals with the statistical parameters defined experimentally. The detection parameters were obtained by a pattern classification theory and a Bayes classifier.



## 1. Introduction

In the last decade many scientific centers have been involved in intensive works on detection of explosive materials (EM) by TNM. In comparison with other neutron methods [1] TNM uses a compact source of 14 MeV high penetrating neutrons with a built-in segmented detector of α-particles. It allows a 3D localization of places of emission of prompt characteristic γ-rays produced as a result of interactions of neutrons with the nuclei of chemical elements of irradiated object. The published papers [2–7] frequently refer to some TNM quantitative indices concerning the detection capabilities of appropriate explosives detection systems that were supposed to provide a potential customer with exhaustive information on the efficiency of the system. They usually claim that a given system is capable of detecting a certain quantity of explosives for a given time [2–4]. Sometimes the distance from the inspected object to the inspection system for which the quantitative indices are valid is stated [4]. More rarely the inspected object is characterized with regard to the presence of legal materials around the explosives. And in a very few cases the type of the explosives for which the measurement were taken can be found. In the reports we failed to find any systematic investigations that would address both the detection capabilities (probability of explosives missing and false alarms) and the weight and type of explosives, the distance from the explosives to the system as well as the presence of shielding materials around it. This article describes a series of measurements that should partly solve this problem. It is self-evident that the experiments themselves cannot answer all possible questions, but they can and must become a ground for numerical simulation and theoretical prediction of detection capabilities in any inspection task. We are also running such studies and they will be published elsewhere.

Here we consider one of options of the inspection task when a hand-held system is used as an explosive detector. In such system the tagged neutron generator and γ-detector are mounted as close as possible to each other and the dimensions of the inspected object do not exceed 20 cm corresponding to the category of hand luggage. It is obvious that even in such a compact geometry the explosives can be shielded by legal materials with chemical composition close to explosives to prevent their detection by conventional X-ray methods. To complicate the task, we propose that a suspicious material is covered with 5 or 10 cm layer of paper (one or two packs of 500 sheets of office paper), which is roughly equal to a half-thickness of the hand luggage. In reality this paper can be substituted by books, booklets, documents, etcetera that can be frequently found in bags and hand luggage of passengers. For comparison, we also carried out measurements without paper shielding.

It should be emphasized that there are Standards, for instance [8], that determine requirements to inspection systems to be used for explosives detection in various types of objects, including hand luggage. In accordance to [8], a system must detect within 60 s an explosive (C4 and ANFO) of 1 kg placed inside a box which has hand luggage dimensions and is filled with newsprint of $0.6_{-20\%}$ g/cm$^3$ density. Despite of that the standard [8] indicates only two explosive materials - C4 and ANFO, we used not only RDX and ammonium

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nitrate imitators which are similar to C4 and ANFO, respectively, but other explosive imitators such as tetryl and TNT. Such extended number of imitators is required for proper definition of indicative boundary between classes of explosive and legal materials.

## 2. Description of the experiment

Fig.1 demonstrates the experimental setup. Table 1 shows the list of materials used as objects to be irradiated by tagged neutron. Note that RDX, tetryl and TNT are presented here not as real explosives but as specially created imitators with appropriate densities and chemical elements composition. The experimental equipment included the ∅3"x3" scintillation γ-detector based on LYSO crystal (Prelude 420, Saint-Gobain), ING-27 14 MeV neutron generator manufactured by VNIIA with a built-in 9-pixel α-detector [9], 20 cm thick tungsten plate prevented γ-detector from direct bombardment of generator neutrons. The inspected object was located strictly within the central voxel which corresponds to the solid angle of the α-detector central pixel. The shielding material being the packs of office paper was positioned in front of the object. It corresponds to the most difficult case of shielding of the object by legal materials as far as the shielding prevents the object from direct irradiation of 14 MeV neutrons and at the same time reduces the response of γ-rays from the object.

The amplitude of γ-detector signal and its time mark relative to the moment of a tagged neutron escape toward the object [5] were measured by digital multi-channel analyzer.

The explosives and legal materials listed in Table 1 were irradiated at a neutron generator intensity of $5\cdot10^7$ n/s three times: without shielding material, with 5 cm (2.5 kg) paper shielding and 10 cm (5 kg) paper shielding during two hours excluding unshielded water, polyethylene, melamine that were irradiated four hours each. The silk pieces were tied tightly to increase material density.

## 3. Processing of the measured data

The direct result of each experiment is a double differentiable spectrum of γ-detector responses $d^2N/dEdT(E,T)$, where $E$ is a γ-detection energy and $T$ stands for a time mark relative to the moment of a tagged neutron start. After the background spectrum of the random coincidences is subtracted [5] and the intervals $dE$ and $dT$ are selected, the measured spectrum can be expressed by the function $\varphi(E,T)$of two discrete variables $E$ and $T$. The γ-spectra $\phi_i(E)$ from interactions of neutrons with individual chemical elements, where $i$ is an element, and the γ-detector response to the scattered neutrons $\phi_{\mathrm{Neutr}}(E)$ can be used for decomposition of the measured spectrum into elemental components $\varphi(E,T)=\sum_{i=C,N,O...,\mathrm{Neutr}}k_i(T)\cdot\phi_i(E)$, where $k_i(T)$ are the coefficients of spectrum decomposition into individual chemical elements depending on the time mark. Finally, the decomposition is presented in the form of two parametric functions $N(T)$ and $O(T)$ that are expressed as: $N(T)=k_N(T)/S(T)$, $O(T)=k_O(T)/S(T)$, where $S(T)=\sum_{i=C,N,O}k_i(T)$ is the sum of decomposition coefficients of only three elements of carbon, nitrogen and oxygen.

In our work the elemental spectra $\phi_i(E)$ were represented by the spectra obtained in the measurements of unshielded materials (Table 1): water (O), melamine (N) and polyethylene (C), as well as the spectrum of scattered neutrons (Neutr) as the γ-detector response to the tagged neutrons scattered by the polyethylene. Fig. 2 gives an example of the spectrum decompositions.

Such spectral decompositions were carried out separately for each 1/2 ns time interval which position corresponds to a point of γ-response from the paper shield and the object. The obtained $N(T)$ and $O(T)$ functions are approximated individually by the function $\Phi(T)=(A+B)/2+(A-B)/2erf\left[(T-C)/D\right]$, where $erf(x)=2/\sqrt{\pi}\cdot\int_0^x\exp(-y^2)dy$, $A$ characterizes the shielded object; $B$ characterizes the shield, $C$ is a time mark separating the shield and the object; $D$ characterizes the time resolution of the measuring system which is estimated as low as $1.3\pm0.1$ ns.

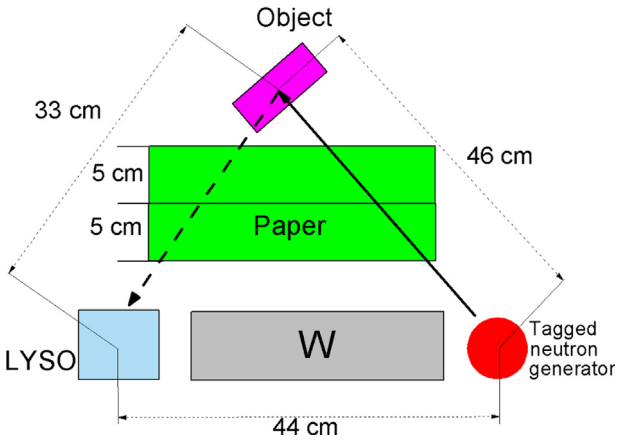


**Fig. 1.** Flow chart of the experiment.

**Table 1**
List of materials used as object (explosive and legal) and shielding.

| № | Material | Weight (kg) | Density (g/cm$^3$) |
|---|---|---|---|
| Explosives | | | |
| 1 | RDX | 0.3 | 1.663 |
| 2 | Tetryl | 0.3 | 1.544 |
| 3 | TNT | 0.3 | 1.585 |
| 4 | Ammonium nitrate | 0.575 | 1.544 |
| Legal materials | | | |
| 1 | Water | 0.49 | 1.0 |
| 2 | Polyethylene | 0.3 | 0.94 |
| 3 | Melamine | 0.55 | 1.074 |
| 4 | Silk | 0.3 | ~0.47 |
| 5 | Sugar | 0.5 | 0.98 |
| Shielding materials | | | |
| 1 | Paper 5 cm | 2.5 | 0.8 |
| 2 | Paper 10 cm | 4.99 | 0.8 |

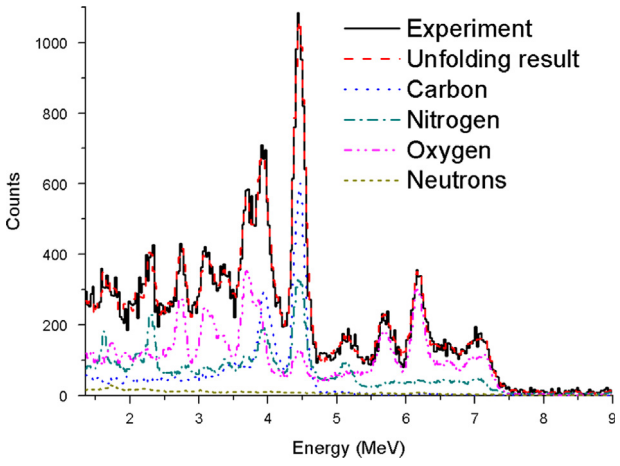


**Fig. 2.** TNT decomposition into elemental components (color online).

Fig. 3 presents a detailed example of time behavior of γ-spectrum decomposition into elemental components and Fig. 4 presents approximation of relevant $N(T)$ and $O(T)$ functions by $\Phi(T)$ function. Thus, $N_A$ and $O_A$ characterize the elemental composition of the object and the $N_B$ и $O_B$ characterize the shielding material. Note that the case of shielding absence is recognized when $abs(N_A-N_B)/\sqrt{\Delta N_A^2+\Delta N_B^2}$ and $abs(O_A-O_B)/\sqrt{\Delta O_A^2+\Delta O_B^2}$ are both below 1.